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AIR COMBAT TARGETING/EO SIMULATION INCORPORATING THE EARTH BACKGROUND

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This report documents some work toward developing an automated Earth background description and putting it into the Air Combat Targeting/Electro-Optical (ACT/EOS) model. Our aim is to show that infrared-based decision aids can be made more accurate by using geographic data sets for terrain type characterization in conjunction with topographic data sets. As an example for digital topography and terrain typing we discuss the digital terrain elevation data (DTED) and a higher resolution Hanscom AFB survey data set. Also described is a methodology for converting rasterized elevation data to a triangular network for perspective viewing.

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1 Introduction

It is now commonly accepted within the US Air Force and the DoD community that computerized decision aids are a necessary tool to supplement human decision making because of the complexity of the modern day military mission. Researchers at the Atmospheric Sciences Division of Phillips Laboratory have been working to develop visual, infrared, and laser electro-optical tactical decision aids (TDA) to supplement the decision making process of the mission planner who schedules sorties bearing precision guided munitions. Quantitative improvements for the TDAs are needed. We have recently focused our attention on the infrared spectrum and have initiated the Air Combat Targeting/Electro-Optical Simulation (ACT/EOS) project [1] using state-of-art software and computer hardware technology, detailed experimental IR calibration and evaluation, as well a robust decision making strategy [2].

A primary component within the ACT/EOS modelling framework is thermal diffusive modeling. This problem has been traditionally divided into two conceptual parts: target and background. Thermal calculations are done independently for the target and for its background. Conceptually, the target and its background are coupled together only through radiant energy transport, a so-called radiosity calculation. In this report we do not attempt to consider whether this modelling concept is generally adequate (under circumstances where thermal diffusive transport of heat energy is substantial, such as a tank

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partially submerged in water, of course it would not be adequate). Instead, working within the framework of this modelling concept, we consider what could be done to improve the thermal background calculation and target-background coupling. The answer we suggest is to improve our description of the background. In the current operational release of the infrared TDA, the user is required to specify the latitude and longitude of the target, its geometrical orientation, the type of background at that location including its slope and aspect. Of course when estimating an IR target-background contrast ratio, getting the right terrain type and topology of the background is essential for the estimate to be at all meaningful. Here we suggest that this part of the decision making process can be automated in a straightforward fashion. Using digital terrain elevation data and a terrain-type classification scheme based on satellite observation, the mission planner need not worry about selecting the right terrain type, complexity of the background, its topology, and even surface conditions such as moisture content; instead this may be provided by pre-constructed geographic data sets. Essentially then the user need choose only the target type, the mission time and location, and all the background information would be "retrieved".

Therefore in this report we discuss some preliminary work and ideas towards incorporating an Earth background that would eventually be incorporated into the ACT/EOS model in a more advanced and sophisticated form. Necessary background input to ACT/EOS comprises of the following topics: terrain elevations, terrain types, and features. This report describes research background data covering these topics. This research data is used strictly for model evaluation and testing. This data should not be interpreted as USAF field system data for a battlefield area or enemy territory.

This report is organized as follows. First, we begin with some general background information on our modelling framework. The next part of the report is dedicated to describing databases applied here. Section 3 discusses digital terrain elevation data (DTED) produced by the Defense Mapping Agency [9]. Next, Section 4 describes high resolution Hanscom Field survey data. It is important that survey work be done to check the validity of terrain-typing algorithms and the Hanscom Field topographic data set is collected primarily for that purpose. Additionally, the Hanscom Field survey work described in this section feeds into the calibration and evaluation effort of the ACT/EOS core algorithms. Section 5 describes the terrain data format and methodology for converting raster data for perspective viewing. Lastly, Section 6 presents a graphic polygonal network standard for handling multiple faceted objects.

2 Background

At Phillips Laboratory we have funded the development of the Mark III Electro-Optical Tactical Decision Aid (EOTDA) IR Sensor Performance Model [3], the Georgia Tech Research Institute (GTRI) 1-D Thermal Contrast Model (TCM2) [4], and Low Resolution Transmittance (LOWTRAN 7) Model. The current TDA consists of input and output processors and three submodels: (1) a target model that determines the inherent signal that emanates from scene objects; (2) a transmission model that estimates the degradation of signal from target to sensor; and (3) a sensor performance model.

A thermal contrast model was developed by Johnson at GTRI [4] [3]. This model describes a target with a hierarchical classification scheme. The target is described as a set of nodes, each node characterized by its geometrical position and physical attributes such as material type and emissivity. The nodal target description layer is used for a thermal analysis calculation. The thermal diffusion equation is solved at the nodal level by a one-dimensional heat diffusion network. All the forcing terms are atmospheric quantities such as sky radiation, convection, mass transfer, and aerodynamic heating, and are connected with an appropriate thermal conductance to the outermost surface layer of a node. The node is described as a multiple layered structure terminating at an interior core temperature boundary point. The model assumes each node is independent from neighboring nodes for the purpose of speeding and simplifying the thermal calculation. That is, heat conduction only occurs normal to the surface node from the atmosphere into the internal target structure, but does not conduct laterally across nodes. In the ACT/EOS project a three-dimensional solution to the heat diffusion problem is being implemented.

The LOWTRAN model [3] [5] [6] [7] [8] provides detailed information about atmospheric transmission and background radiance along a path through the atmosphere. Various geometries are possible; however, because of the tactical focus, we have been primarily concerned with slant paths originating at low altitudes, on the order of a few kilometers, to the surface.

The target data comprises approximately 42 faceted target files, such as tanks and helicopters, produced for Phillips Laboratory by Georgia Tech Research Institute (GTRI). Tabulated target data includes the percentage of viewable surface node area from 370 observer points in the upper hemisphere, a radiation conductor network, target facet information including the total number of nodes, constant temperature nodes, radiation nodes, nodes requiring individual starting temperature and heat rates, time dependent heat rate curves, non-radiation conductors, temperature or time dependent properties for conductance and capacitance, and natural and forced convection records. Target geometry is

encoded in as a hierarchical polygon network description with thermal nodes subdivided into radiation nodes.

3 Digital Terrain Elevation Data

The Defense Mapping Agency (DMA) [9] is beginning to make available, on a restricted basis, its 3 arc-second Digital Terrain Elevation Data (DTED) stored on CDROM†. This new storage medium makes accessibility and processing of these data for use in numerical models much easier than in the past. The data are obtained mainly using photogrammetric techniques on aerial photographs. The data is stored on 60 to 70 compact disks (CD's). Most of the northern hemisphere is included, but little of the southern hemisphere is available.

Each CD contains up to 288 files. Each file consists of an array of 3x3 arc-second box average elevations in meters (that is, 1200×1200 heights per file) covering a one degree of latitude by one degree of longitude area. Because of the spherical shape of the Earth, the DTED sampling changes with latitude: 3x3 arc-second sampling for the 0 to 50 degree North and South latitudinal intervals, 3x6 for the 50 to 70 intervals, 3x9 for the 50 to 70 intervals, 3x12 for the 75 to 80 intervals, 3x18 for 80 to 90 intervals. For accuracy, each file includes an additional elevation overlap in each direction.

The absolute accuracy stated by DMA is 130 meters in the horizontal and 30 meters in the vertical. Sea/ocean elevation is listed as 0. Open water, such as large lakes with a diameter of 1200 meters or more, is listed by its surface elevation. Coastlines are required to be higher than adjacent water levels. Extremely shallow land areas are listed as 1 meter to force land boundary portrayal. Islands greater than 600 meters ground distance are included and smaller islands if their elevation is 15 meters. Negative elevations are included for landforms and water bodies whose elevations are below mean sea level.

The CD's are written in ISO 9660 format. Each file contains some 3436 bytes of header information before the one degree by one degree elevations. Included in this header is the following: the latitude and longitude of the southwest corner of the one degree by one degree area encompassed by the file, the hemispheric designation, the count of each south to north 3 arc second record, and accuracy counts and other miscellaneous information.

Sample DTED are given in Figure 1 for Mount Washington in New Hamsphire. A larger region of DTED data for Cape Cod Massachusetts is illustrated in the Figure 2 which has

†PL/GAA receives digital terrain elevation data (DTED Level 1) and digital features analysis data (DFAD Level 1) from the Defense Mapping Agency (DMA) through the US Air Force liaison at Rome Laboratory (RL/IRRP). This data may be also requested from Director, DMA Aerospace Center, 3200 So. Second St., St. Louis, MO 63118-3399.

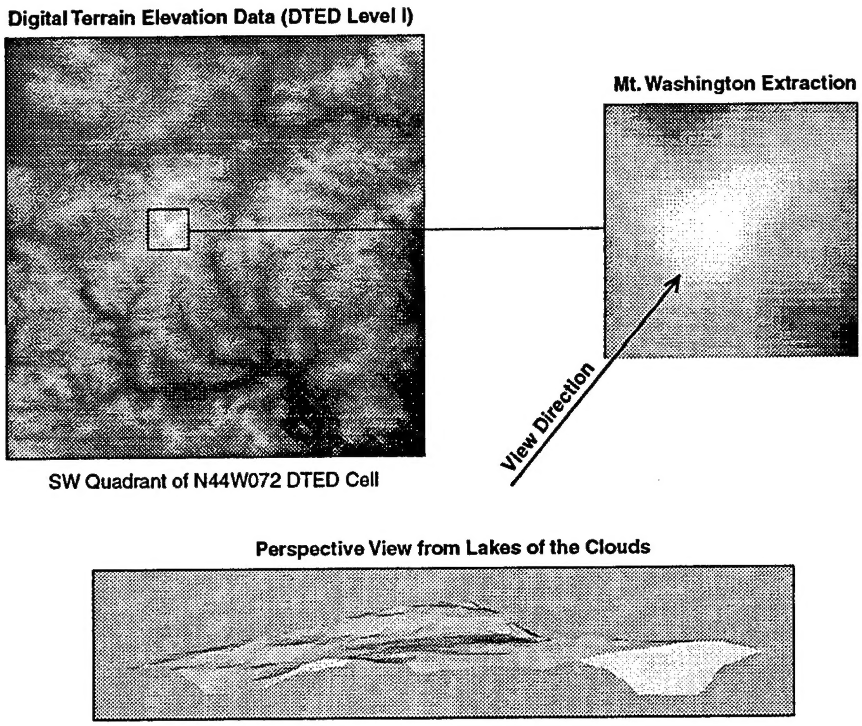

Figure 1: Overhead and Perspective View of Mt. Washington, NH

been presented by Ward, et. al. [10].

4 Hanscom Field Topographic Data

In addition to the DMA data sets, a detailed topographic data set for Hanscom AFB has been included. It is considered to be a test site data set in support of the PL/GPAA Sensor Suite.

Currently, Salem State College (SSC) is conducting a field survey of Hanscom AFB for the purpose of providing a detailed background database used to evaluate and calibrate the terrain model. Figure 3 gives an aerial view of the area surveyed by SSC students through an inovative directed student program called Project Tellus set up between the Air Force and the state of Massachusetts.

The field survey uses Global Positioning Systems (GPS) and digital image processing to develop both topographic and vegetative data sets. The GPS employs the NAVSTAR satellite constellation operated by the Department of Defense (DOD) to provide precise timing signals transmitted to hand-held receivers. The differential timing sequences between signals sent (from satellite) and received (collected by hand-held units) are converted to positional coordinates and elevations with an accuracy of 2.5 meters. By collecting at

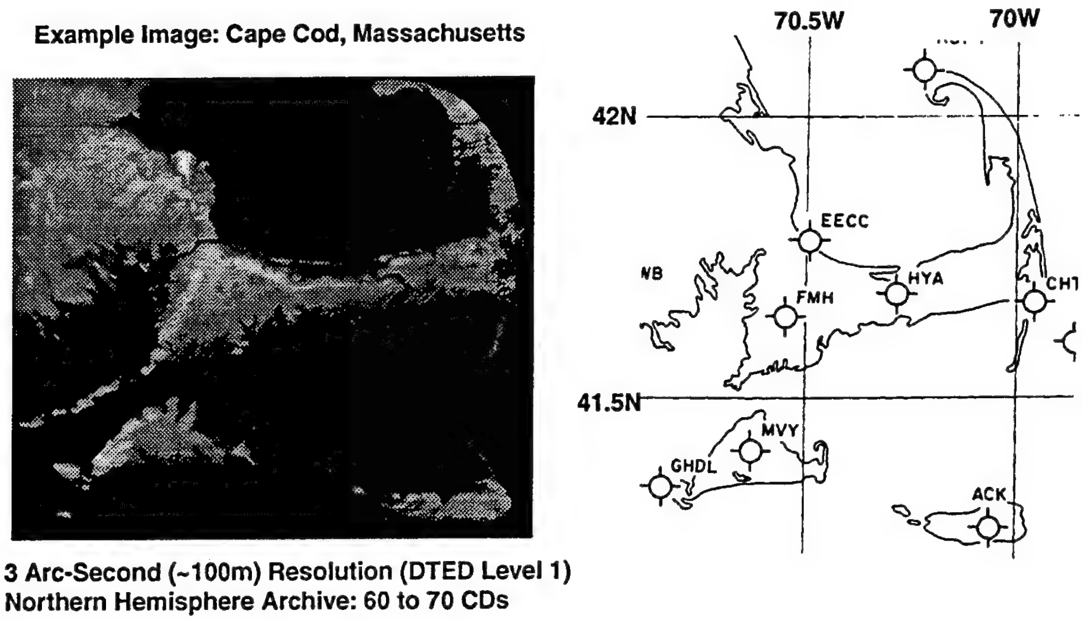

Figure 2: DTED Elevations for Cape Cod, MA

multiple locations, the receivers can also calculate angles and distances. A field survey is conducted by locating the hand-held receivers at desired locations (corners of buildings, center line of roads, etc.) where coordinates and elevations are collected and automatically stored in the receiver's data logger. This field information is then downloaded to a computer, differentially corrected, plotted, and verified. The purpose of the field survey is to collect a sufficient number of control points to geometrically rectify existing base maps to a higher level of accuracy necessary for sensor calibration purposes.

SSC is also working with Digital Features Analysis Data (DFAD Level 1) which Phillips Laboratory received from the Defense Mapping Agency and with vegetation data received from EOSAT, a commercial vendor of LandSat data.

Vegetation and land use information for Hanscom AFB is generated by employing digital image processing of the LANDSAT 5 satellite Thematic Mapper (TM) data. Figure 4 is a false color TM image of a September scene at Hanscom Field, Massachusetts. The TM system numerically encodes the signal strength of electro-magnetic radiation received from earth targets in seven electromagnetic bands with various center wavelengths in the range from 0.48 to 12.5μm. These seven bands are represented as digital numbers which taken as a whole comprise the spectral signature of the target. Each digital scene is 15 km^2 and is geometrically and radiometrically rectified. Each scene has a pixel resolution of approximately 28m.

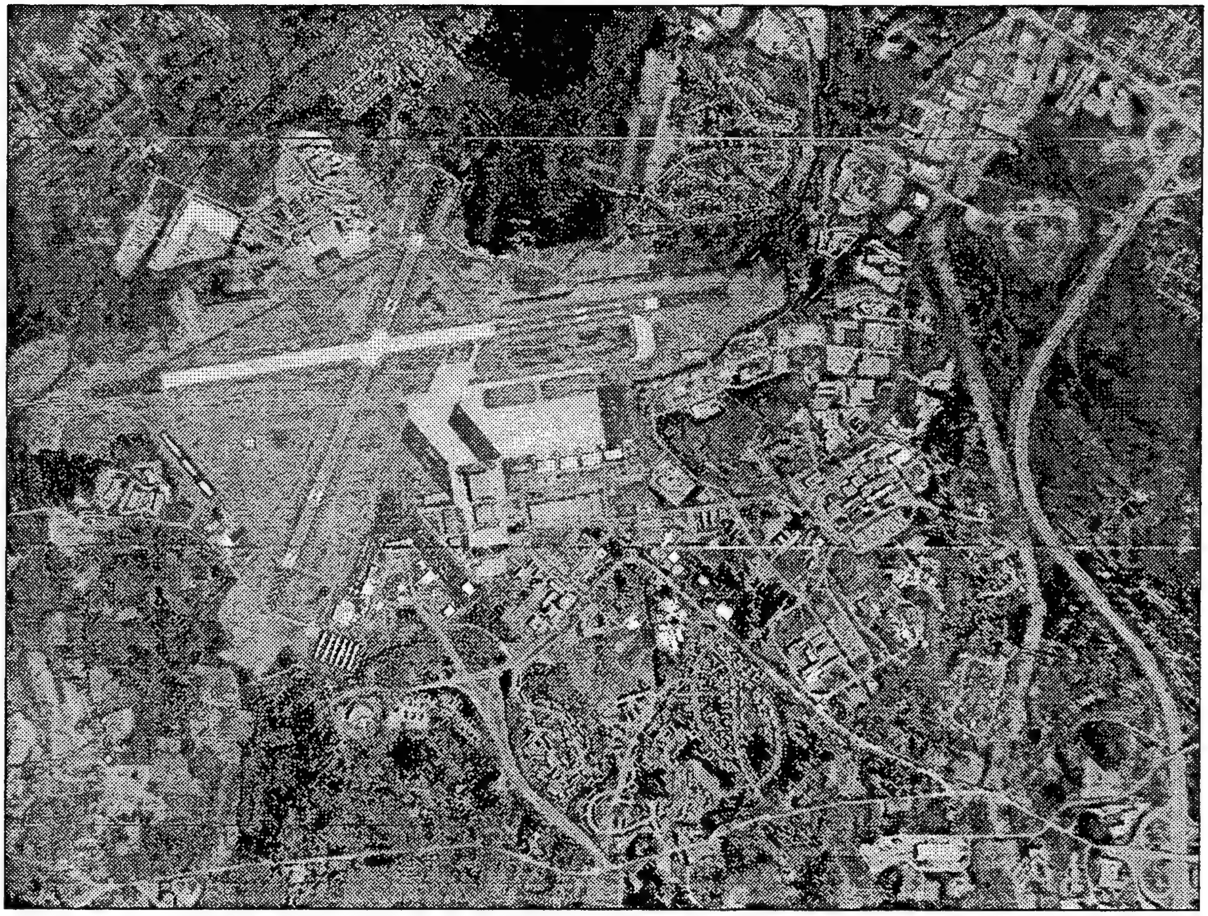

Figure 3: Aerial Photograph of Hanscom AFB, MA

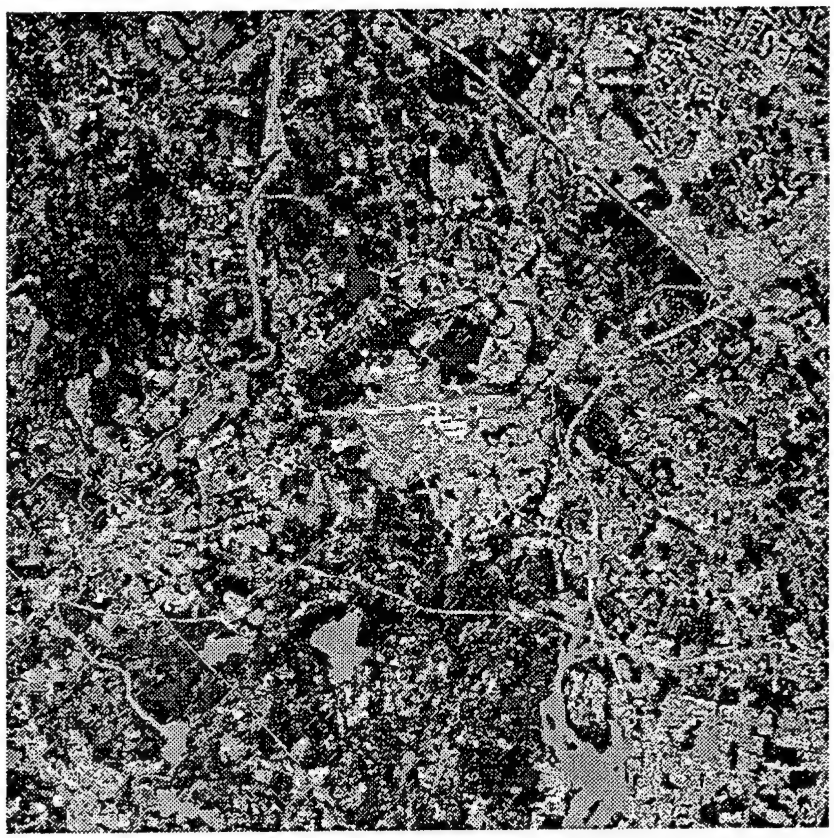

Figure 4: False Color Image of Terrain Types at Hanscom Field, MA

Table 1: Unsupervised Thematic Mapper Classifications

Cluster Number	Classification
1	hardwoods
2	mixed woods
3	wooded swamp
4	brush lands
5	softwoods
6	agriculture/grass
7	shallow fresh water/grass
8	residential, yards/roads
9	water
10	mix of roads/trees 1
11	mix of roads/trees 2
12	agriculture
13	residential/yards & grass
14	type of grass
15	light colored asphalt (with tops of buildings)
16	fallow river area - med. density single family housing
17	smaller service roads
18	industry/urban - med cluster gov. building, parking lots
19	road bed materials undefined
20	dark asphalt
21	exposed soil
22	asphalt
23	base housing
24	roads - dark asphalt
25	concrete runway

The analysis process is the following. First, an unsupervised classification of the digital scene using clustering algorithms on the various wavelength bands is developed. Usually this generates a scene which separates ground targets into broad spectrally defined categories (water, roads, deciduous and coniferous vegetation, etc.). Using first and second order field verification the unsupervised classification for Hanscom generated 26 different vegetation/land-use categories. The unsupervised thematic mapper classifications are listed in Table 1. Note that the classifications presented here represent a classification based on indirect ground verification† and not the field verified classification. Part of the analysis process is to collect field measurements at a statistically significant number of sites (training sites) and match those to pixel spectral digital data. The spatial match of field

†By indirect ground verification we mean the use of survey maps, aerial photos, and the like.

location to scene pixel location is accomplished with the GPS. The digital spectral response for each training site is collected and statistically validated. This match of spectral signatures to field verified targets creates a spectral profile for digital scene identification. Once the desired number of spectral profiles have been produced a supervised classification is engaged. In this case, each scene pixel is digitally matched to a spectral profile generated from field verification. If a match cannot be found the pixel is marked as unclassified. This supervised approach allows for greater stratification of the spectral responses. For example, given adequate field data, a supervised classification yields information on vegetation species type, density, age, type of understory, and health. Thus the supervised classification process allows for the extraction of larger amounts of information as selected by field verification. It is expected that approximately 54 different vegetation/land-use categories for the Hanscom AFB scene can be generated using the classified approach. Operationally, these highly stratified categories may be agglomerated based on need and model response. However, the larger subject stratifications will be necessary for sensor calibration and testing.

Table 2: Revised Unsupervised Thematic Mapper Classifications

Cluster Number	Classification
1	Deciduous
2	Coniferous
3	Mixed Coniferous and Deciduous
4	Grass, Tall
5	Grass, Short
6	Sand
7	Soil, Bare
8	Concrete
9	Asphalt
10	Water
11	Residential
12	Commercial

A revised terrain data set has been developed, using the LandSat Thematic Mapper, with a more limited set of background types that correspond exactly to the types that can be modelled in the current version of the terrain thermal model, see Table 2 for a listing of the terrain categories. Figure 5 illustrates how this data set can be used to isolate certain geographical features. In this case by rendering only the asphalt and concrete terrain types, the location of the airport runways and and a main highway (Route 128 in this case) is clearly seen.

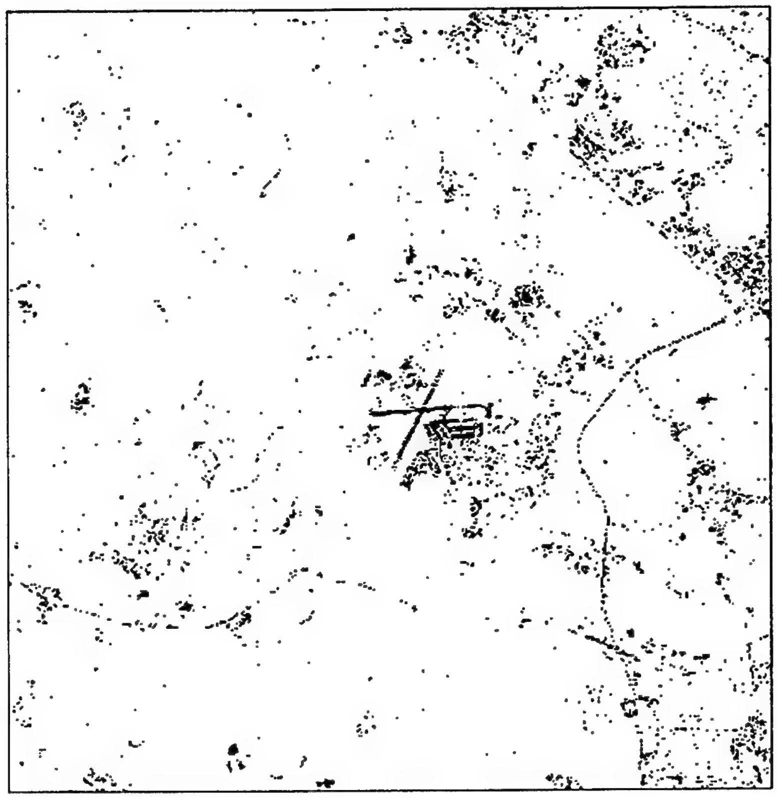

Figure 5: Asphalt and Concrete Terrain Types at Hanscom Field, MA

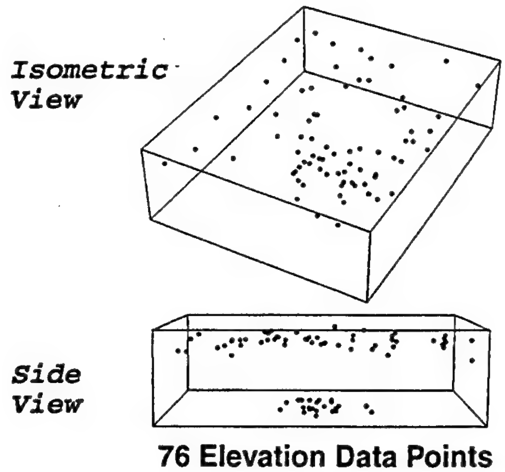

Figure 6: Elevation Samples for Crater Lake, OR

5 Terrain Data Format and Methodology

The case example is a terrain scene using Crater Lake, Oregon elevation data as a prototype. Figure 6 shows 76 non-uniformly sampled elevations from Crater lake.

The non-uniform set was interpolated over a uniform rectilinear grid of 2501 lattice site points shown in Figure 7.

Every four neighboring points of the interpolated lattice define two right triangles. The slope of the triangular polygon is determined by the elevation of its vertices. A perspective viewing direction may then be chosen where the terrain polygons are sorted and rendered according to that view direction. The resulting terrain landscape is depicted in Figure 8.

We are currently interested in archiving global background data to serve as an automated model input, relieving the user from the task of specifying terrain attributes such as slope, aspect, elevation, and terrain type.

6 Graphics Applications

A required component of ACT/EOS is graphics. Rendering of imagery and data sets is the final step in the long simulation march. The goal is to develop a custom graphical application for scene depiction. A polygonal network format has already been developed for composite scenes, including targets, clouds, terrain, and the like. The code is written in

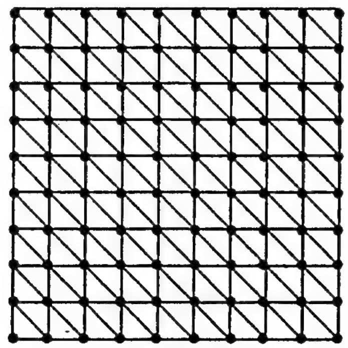

Figure 7: Bilinear Interpolation Grid

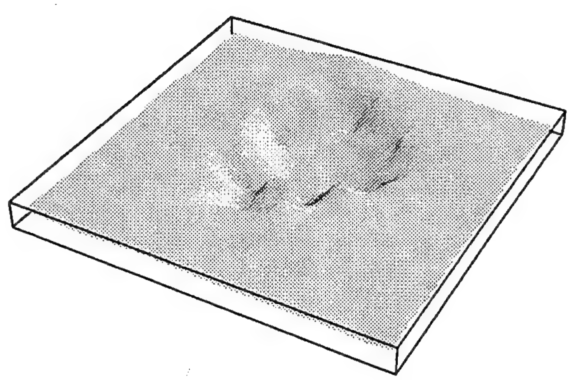

Figure 8: Crater Lake in 3D Perspective

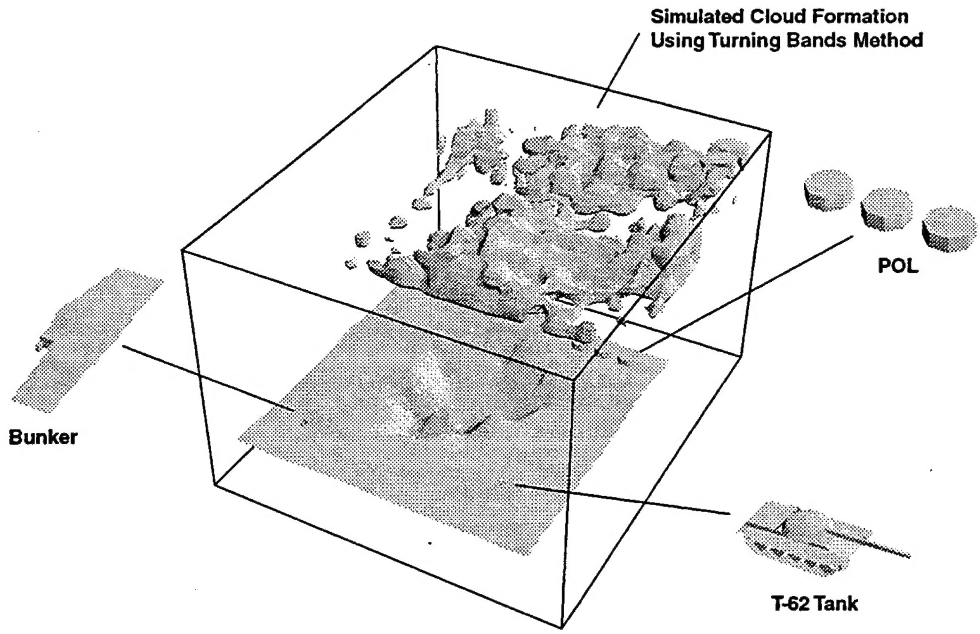

Figure 9: Sky, Earth, and Targets Composite Scene

Mathematica [11] because of its flexible three-dimensional graphics rendering. Also incorporated is a surfacing package (Isosurf) developed by TASC under contract with Phillips Laboratory which produces a triangular-network using the marching-cubes algorithm [12] given a binary three-dimensional raster field. Figure 9 illustrates the standard polygonal network file standard which allows for the incorporation of all elements of the simulated scene, sky, Earth, and target objects. These objects can all be handled in a unified file format amenable to diffusion and radiosity calculations.

7 Conclusion

Presented is this report are some preliminary results on incorporating an Earth background into the ACT/EOS framework. In the Hanscom Field survey, improvements and verifications are still in progress for the terrain typing. In the future we should explore using reflectivity measurements directly, instead of only using the multispectral satellite soundings to do terrain classifications and then finding a standard reflectivity value from a prepared table. That is, the satellite sounding data could be used in much more direct fashion. Moreover, additional information that can be extracted should be used for our project, in particular estimates of ground moisture content. In this paper we have also described a methodology for converting rasterized elevation data to a triangular network suitable for

perspective viewing. Provided is a sample composite image with multiple images encoding in a standard triangular network format. We hope that the information presented here will provide the scope for and stimulate further geographical research within our Atmospheric Sciences Division to further enhance the infrared computerized decision aid product. Exploiting the science and technology of geography and remote sensing provides a direct path for us to improve and partially automate our models. Special thanks go to Joan Ward of Systems Resources Corporation, Bedford, Massachusetts who contributed Section 3 of this report and to Dr. William Hamilton of Salem State College, Geography Department, Salem, Massachusetts who contributed Section 4. The author gratefully appreciates their contributions and collaboration.

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